

membership. An object is classified by a plurality vote of its neighbors, with the object being assigned to the class most common among its  $k$  nearest neighbors ( $k$  is a positive integer, typically small). If  $k=1$ , then the object is simply assigned to the class of that single nearest neighbor. (2) In  $k$ -NN regression, the output is the property value for the object. This value is the average of the values of  $k$  nearest neighbors.  $k$ -NN is a type of instance-based learning, or lazy learning, where the function is only approximated locally, and all computation is deferred until classification. The  $k$ -NN algorithm is among the simplest of all machine learning algorithms.

[0073] In some embodiments, the method may further include detecting a liveness gesture. The liveness gesture is based on at least one of a yaw angle of a second image relative to a first image and a pitch angle of the second image relative to the first image, wherein the yaw angle corresponds to a transition centered around a vertical axis, and wherein the pitch angle corresponds to a transition centered around a horizontal axis.

[0074] FIG. 6 shows an example interface of a search application on a mobile device displaying candidate images in the databases matching the captured facial images. After performing a facial recognition process, the system may identify one or more candidate images that match the captured facial images. The system may rank the candidate images based on a scoring algorithm. For example, the degree of match can be measured as a “distance” value (e.g., Euclidean distance). The smaller distance value indicates a higher degree of match between a given candidate image and the captured facial image. The system may display the candidate images on a user device. Additionally, the system displays relevant information about the candidate image, for example, name, employer, links to webpages where the candidate image can be found, etc. The user may select a candidate image that is thought to a correct match. Upon receiving a user response of selecting a particular candidate image, the system will display additional information related to the selected candidate image.

[0075] As shown in FIG. 7, the additional information about the candidate image may include: name, title, link to an online profile. The online profile can be a social network profile (e.g., Facebook, Google+), a professional network profile (e.g., LinkedIn) or an employee profile on an employer’s website. Additionally, the system may also display the distance value to indicate the degree of match.

#### E. Neural Network-Based Facial Recognition

[0076] In some embodiments, the system may employ a machine learning module for facial recognition. The machine learning module may employ any one of the following algorithms, including, without limitation, deep convolutional neural network (CNN), support vector machines (SVMs), neural network, logistic regression, naive Bayes, memory-based learning, random forests, bagged trees, decision trees, boosted trees, boosted stumps, etc. Some embodiments of the machine learning module use unsupervised machine learning that provides training data without labeled responses. Examples of unsupervised machine learning techniques use clustering, for example,  $k$ -means clustering, hierarchical clustering, and so on.

[0077] Neural network technology, also known as “artificial neural network (ANN),” is one of the most developed tools used in machine learning modules for pattern recog-

nition. Neural networks are constructed of processing elements known as neurons. Neurons are interconnected and arranged in a plurality of layers. Each neuron can have multiple inputs but generally only one output, which, in turn, is usually connected to many or all other neurons in the next layer. Neural networks learn by extracting relational information from the data and the desired output. A neural network in the machine learning module is initially trained or fed large amounts of data. In some embodiments, the machine learning module may employ a plurality of neural networks, which may be organized either in series, in parallel, or in a nested fashion. For example, a primary neural network may identify an abnormality of a chassis component and attempts to identify the possible source. The neural networks can be arranged in a tree pattern or in a hierarchical structure, with each neural network trained to perform a particular pattern recognition task. A group of such neural networks may be coupled to other groups of neural networks to handle more complex tasks.

[0078] FIG. 8 shows an example of a neural network used for facial recognition. Initially, the system may receive and preprocess facial image data, for example, from a user device and analyze the preprocessed data with a machine learning module implementing a neural network algorithm. The facial image data directed to the features of a face are fed into nodes  $N1$  through  $Ni$  in the input layer.

[0079] Each of the input nodes is usually connected to each of the nodes in the second layer (e.g., a hidden layer),  $H1$ ,  $H2$ ,  $H3$ ,  $H4$ , . . . , and  $H_i$ , through, for example, mathematical functions containing multiplying coefficients (also known as weights). At each hidden layer node, a node value may be obtained by summing the values from each of the input layer nodes, which have been operated on by functions containing the weights. Likewise, the hidden layer nodes are, in turn, connected to the nodes in the second hidden layer,  $L1$ ,  $L2$ ,  $L3$ ,  $L4$ , . . . , and  $L_i$ . The node values of the nodes of the second hidden layer are similarly generated as above described. The nodes of the second hidden layer are connected to the output layer node(s). In this example, only a single node  $O$ , representing the decision to notify the driver, and/or a remote service center, of the unbalanced tire. The output value from the output layer node may have various forms. For example, an output node value of 1 may be assigned to indicate that the driver/service center should be notified, and a value of 0 may be assigned to indicate that the driver/service center should not be notified.

[0080] Generally, in identifying matching candidate images for the captured facial image, the system may: (1) first acquire facial image data from a user device; (2) preprocess the acquired facial image data, such as digitalizing the facial image data and/or vectorizing the facial image data; (3) feed the preprocessed facial image data to a facial recognition module implementing a machine learning algorithm (e.g., a facial recognition algorithm); (4) process the facial image data using the machine learning algorithm to detect characteristic features of a face; (5) identify one or more matching candidate images and the information associated with the one or more candidate images; and (6) optionally alert the user is a person of interest. A person of interest may include a person announce missing, a person accused of a crime, a person with a criminal record, a sex offender, a person who has suffered memory loss, and a person who may otherwise pose a high risk to the public.